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PRINCIPAL INVESTIGATOR: Lawrence B. Marks, M.D.

CONTRACTING ORGANIZATION: Duke University Medical Center
Durham, North Carolina 27710

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13. ABSTRACT (<i>Maximum 200 Words</i>) Purpose: To determine the incidence and dose-dependence of regional cardiac perfusion abnormalities in patients with left-sided breast cancer treated with radiation therapy (RT) with and without doxorubicin. Methods: 114 patients with left-sided breast cancer underwent cardiac perfusion imaging using single photon emission computed tomography (SPECT) pre-RT. Post-RT images were obtained in 80, 47, 23 and 9 patients 6, 12, 18, and 24 months post-RT. SPECT perfusion images were registered onto 3-dimensional (3D) RT dose distributions. The volume of heart in the RT field was quantified and the regional RT dose was calculated. A decrease in regional cardiac perfusion was assessed subjectively by visual inspection and objectively using image fusion software. Results: Overall, 40% of patients developed RT-induced perfusion defects. The incidence of such defects increased with increasing volumes of the heart irradiated, increasing duration of follow-up, and were more prevalent in African American patient (vs. caucasians) and in those receiving chemotherapy (vs. RT alone). The severity of the defects appears to be dose-dependent. No events of myocardial infarction (MI) or congestive heart failure (CHF) have occurred. causes dose-dependent cardiac perfusion defects 6-24 months post-RT in most patients. The use of chemotherapy and African race may increase this rate. Long-term follow-up is needed to assess whether these perfusion changes are transient or permanent and mine if these findings are associated with changes in overall cardiac function and clinical outcome.				
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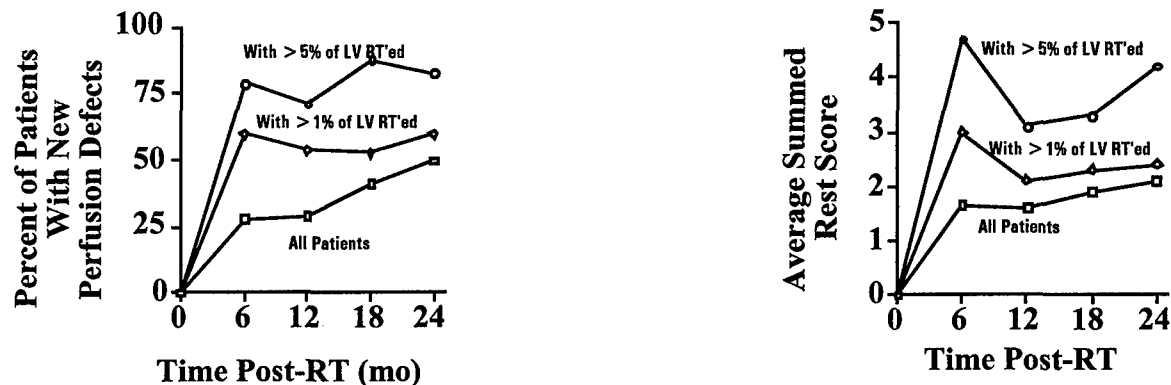
Introduction:

With the increasing use of radiotherapy in the management of primary breast cancer, there has been rising concern about long-term side effects of radiation therapy. Some randomized series evaluating patients irradiated post-mastectomy report an excess number of cardiovascular deaths in the irradiated group (1). Additionally, radiotherapy to the heart in conjunction with the chemotherapy drug doxorubicin (Dox) appears to increase the risk of developing cardiac damage (2). New 3D radiation treatment planning tools provide the opportunity to know the 3D RT dose distribution in any tissue. Doses can be calculated for complex field arrangements and differences in tissue density may be considered (3). SPECT cardiac perfusion imaging provides a noninvasive assessment of myocardial perfusion and function. Advances in image registration allow us to superimpose the 3D dose distribution onto noninvasive nuclear medicine 3D cardiac imaging studies (4). Using 3D treatment planning tools and nuclear medicine perfusion imaging of the heart, we attempted to define the volume of left-ventricle in the RT treatment field, and correlate regions of post-RT perfusion changes with both the RT dose and the use of Dox-based chemotherapy.

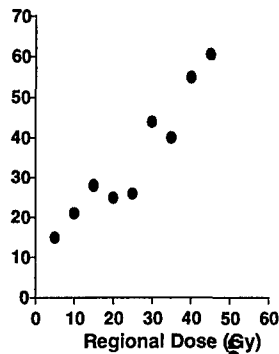
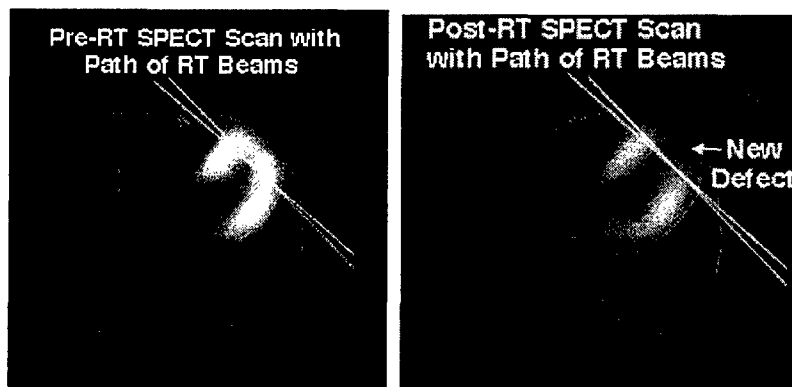
Body: Data Presentation, Research Results:

Between 1998-2001, we have enrolled 114 patients onto this clinical trial to assess RT-induced changes in regional and global cardiac function. The median age was 57 (range 33-82), 15 were AA, and 79 received chemotherapy prior to RT. Of these, 80, 47, 23, and 9 patients have follow-up data at 6, 12, 18 and 24 months post-RT, respectively. Not all patients are evaluable at all intervals due to patient attrition (19 refused to have FU scans); some FU scans are pending, and some scans have not yet been analyzed.

Visual evaluation of the SPECT scans (specific aim # 1 and 2): The presence and severity of defects were scored by a nuclear medicine radiologist based on a 12-segment model scoring system (summed rest score [SRS]; see Methods). The incidence of new perfusion defects for the entire population, and those whose percent of LV included in the RT field exceeded > 1% or > 5%, is shown for different post-RT intervals. Defects are more common in patients with larger volumes of the LV irradiated. In the patients with < 1% of their LV within the RT field, no new defects were detected. Similarly, the SRS scores over time are shown.

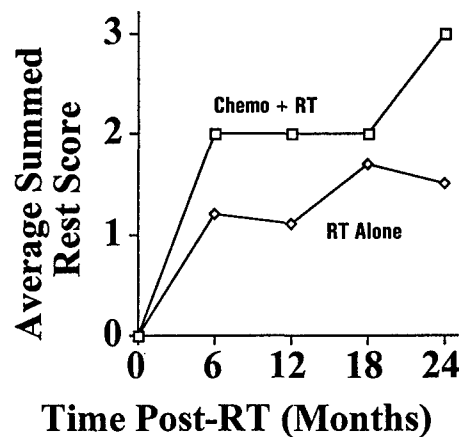


Quantitative analysis (specific aim # 1 and 2): The pre- and post-RT SPECT scans were registered with the 3D dose distribution from the planning system. Within each pixel of the LV, quantitative changes in regional perfusion were compared to the regional dose (see Methods). An example of a single patient's pre- and post-RT axial SPECT image is shown. There is a clear reduction in perfusion within the RT field on the post-RT image. The associated patient-specific dose response curve (DRC) is shown.

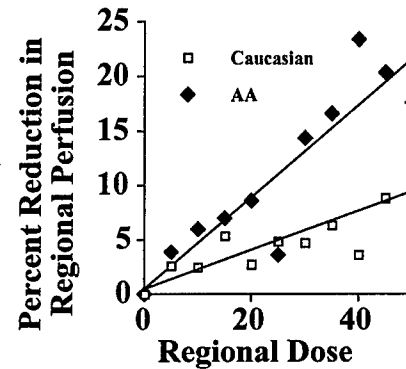
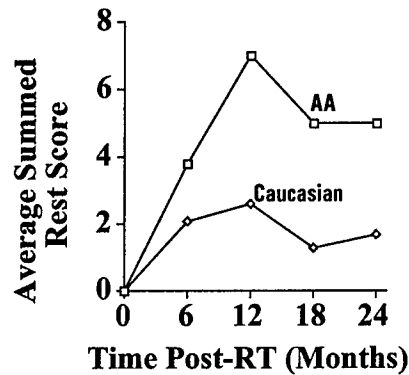


Similar data were generated for each patient at each follow-up evaluation. Population DRCs are calculated by pooling the data from multiple patients. The population 6-month DRC is shown. There is a clear dose-dependent reduction in regional perfusion ($p < 0.0001$).

Impact of chemotherapy (specific aim # 1 and 2): The severity/extent of RT-associated perfusion defects, as measured visually by the SRS, was greater in the 49 patients who received adriamycin-based chemotherapy prior to RT, versus those treated with RT alone (Hardenbergh 2001), although the number of evaluable patients at the later follow-up intervals was small. Similarly, patients who received adriamycin (total dose 240-300 mg/m²) prior to RT had a slightly steeper DRC (i.e., a greater decrease in regional perfusion) than patients treated with RT alone.



Impact of Race: The visual comparison of serial scans by a nuclear medicine radiologist shows an increase in the severity and extent of perfusion defects (SRS) in AA's vs. Caucasians. Similarly, quantitative analysis shows a steeper DRC for AA's than the Caucasians at both 6 and 12 months (6-month data shown below).



Relating changes in regional perfusion to changes in regional and global LV function (specific aim # 3):

Regional Function: 19% of patients with new perfusion defects 6-months post-RT had corresponding wall-motion abnormalities. All of these involved the anterior portions of the LV, thus corresponding to the RT portal. Thus, regional perfusion defects may be accompanied by regional functional changes.

Global Function (EF): No patient has had an infarction or experienced congestive failure, though followup is short in most patients. Five patients had their ejection fraction drop to < 50%, and six had an absolute decline of >10 percentage points in their EF (11, 13, 16, 17, 17, and 23 absolute declines in EF). This 10% threshold is chosen somewhat arbitrarily since smaller declines may be related to normal physiologic variations and/or inaccuracies in the measurement of EF.

To explore the ability of 3D treatment planning in designing treatment beams for patients with left-sided breast cancer to achieve a reduction in the volume of the heart receiving radiation compared to a conventional 2D clinical set-up (specific aim #4): In a series of 20 patients, a formal comparison was made between RT fields that were designed using 3D planning software, and RT fields defined using our conventional methods (CT-based, but without 3D planning software). In patients wherein the internal mammary nodes were to be irradiated, there was a suggestion that the 3D planning tools were helpful in minimizing the volume of heart irradiated. In the group of women where the intention was to treat the breast alone, there was not benefit of 3D planning.

Difficulties in Accomplishing Tasks:

The preliminary data suggests that there might be an impact of race on the outcome. However, there are a limited number of African American patients evaluable on this study. This will be addressed by enrolling additional AA patients in the future. Some of the patients have elected not to have additional post-RT scans, and this has modestly reduced the number of evaluable patients. The vast majority of patients remain evaluable.

In May of 2001, the primary investigator, Dr. Patricia Hardenbergh, left Duke. Dr. Lawrence Marks, a co-investigator, became the primary investigator. IRB approval was obtained.

Recommended Changes or Future Work:

This work will continue under the recently-approved Clinical Bridge Award. That study will assess the longer-term changes in cardiac perfusion following RT, the possible roles of chemotherapy and race in RT-induced heart injury, and the functional consequences of perfusion changes.

In future work, consideration will be given to using additional imaging modalities of the heart. We would anticipate using serial MR images to assess for regional micro-vascular cardiac perfusion (similar to what is provided by SPECT) as well as MRI based assessments of the regional inflammation, metabolic activity, and coronary artery blood flow.

Similarly, positron emission tomography (PET) possibly might provide quantitative data relating to regional metabolism in the heart. When this technology is more readily available, we anticipate including serial PET evaluation in these patients. Serial PET scans will be compared to each other, in a similar fashion to how serial SPECT scans are to be analyzed.

Key Research Accomplishments:

- We have established the first dose-response curve for RT-induced perfusion defects in the heart.
- We have defined the time-dependence of these perfusion changes for the first 2 years following RT.
- We have observed that RT-induced cardiac injury might be more prevalent in patients who also receive chemotherapy (vs. RT alone) and in African Americans (vs. caucasians).
- We have demonstrated that these perfusion defects may be associated with wall motion abnormalities, but that clinically-significant cardiac dysfunction/symptoms have not been observed.
- We are showing the importance of sophisticated radiation therapy treatment planning (3-D) for patients with left-sided breast cancer. This may be particularly relevant for patients with left-sided breast cancer who have received chemotherapy.

Reportable Outcomes:

Manuscripts and Abstracts:

Munley MT, Marks LB, Hardenbergh PH, Bentel GC: Functional imaging of normal tissues with nuclear medicine: Applications in radiotherapy. *Seminars in Radiation Oncology* 11(1):28-36, 2001.

Marks LB, Bentel GC, Hardenbergh PH, Lind PAR, Prosnitz LR. A practical and easy method to locate the first three internal mammary lymph-node bearing areas. *Int J Radiat Oncol Biol Phys* 50(2):421-425, 2001.

Hardenbergh PH, Munley MT, Bentel GC, Kedem RR, Borges-Neto S, Hollis D, Prosnitz LR, Marks LB. Cardiac Perfusion Changes in Patients Treated for Breast Cancer with Radiation Therapy and Doxorubicin: Preliminary Results. *International Journal of Radiation Oncology Biology, Physics* 49:1023-1028, 2001.

Hardenbergh PH, Munley MT, Bentel GC, Strickland J, Borges-Neto S, Hollis D, Prosnitz LR, Marks LB: Pathophysiologic impact of doxorubicin (Dox) and radiation therapy (RT) on the heart of patients treated for breast cancer. *Proceedings of the 41st Annual ASTRO Meeting. Int. J. Radiat. Oncol. Biol. Phys.* 45(3) (Suppl):197, 1999.

Hardenbergh PH, Munley MT, Hu CY, Borges-Neto S, Hollis DR, Marks LB: Breast cancer treatment related myocardial damage appears increased in African-American Women. *American Society of Clinical Oncology, Thirty-Seventh Annual Meeting, San Francisco, CA, May 12-15, 2001. ASCO* 20 (1 of 2):29a, 2001.

Lind PA, Pagnanelli R, Marks LB, Hu C, Borges-Neto S, Hardenbergh PH. Myocardial perfusion changes in patients treated with left-sided breast cancer and correlation with coronary artery distribution. *ASTRO 43rd Annual Meeting, San Francisco, CA, Nov. 3-7, 2001. Int J Radiat Oncol Biol Phys* 5(suppl 1):157-158, 2001.

Hardenbergh P, Munley M, Hu C, Hollis D, Light K., Blazing M, Borges-Neto S, Marks L. Doxorubicin-based chemotherapy and radiation increase cardiac perfusion changes in patients treated with left-sided breast cancer. ASTRO 43rd Annual Meeting, San Francisco, CA, Nov. 3-7, 2001. Int J Radiat Oncol Biol Phys 5(suppl 1):158, 2001.

Funding:

Based on the results of this work, we will have submitted a Clinical Bridge grant to the DOD entitled: Treatment-Related Cardiac Toxicity in Patients Treated for Breast Cancer. This study will assess the longer-term changes in cardiac perfusion following RT, the possible roles of chemotherapy and race in RT-induced heart injury, and the functional consequences of perfusion changes.

Clinical Relevance:

- Treatment of left-sided breast cancer may be effected by the results of this study. The development of 3-D treatment planning to limit treatment-induced heart damage may become more widely applied.
- A better understanding of RT-induced cardiac dysfunction (with or without chemotherapy) may help us better plan therapies for women with breast cancer.
- While this study addressed only patients with breast cancer, its findings are applicable to patients with other diseases as well. Recognition of RT-induced cardiac dysfunction, and its dose/volume-dependence, may impact on therapy for patients with cancers of the lung, esophagus, mediastinal tissues and upper abdomen.

Conclusions:

RT induces dose-dependent changes in regional cardiac perfusion within the region of heart irradiated. This suggests that RT may cause microvascular damage to the heart. To date, there have been no clinically-relevant cardio-toxic events observed, and thus the clinical importance of these perfusion changes remains unclear. The incidence of these perfusion defects appears higher in patients who also receive chemotherapy (vs. RT alone) and in African Americans (vs. caucasians). Additional follow-up of the current cohort of patients, plus the study of additional patients, will help determine if these perfusion defects are persistent, if they have long-term clinical significance, and the role of chemotherapy and race in their evolution.



DEPARTMENT OF THE ARMY
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REPLY TO
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Deputy Chief of Staff for
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